

# **SIDE AIRBAGS: EVALUATING THE BENEFITS AND RISKS FOR RESTRAINED CHILDREN**

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## **ABSTRACT**

Child dummies were seated in size appropriate child restraints and exposed to in-vehicle, static, side mounted airbag deployments as well as full scale side impact crash tests.

The child seat sample included rear and forward facing child restraints and booster seats. Anthropomorphic test dummies (ATD) included an 18 month infant and fully instrumented Hybrid III 3 year old and Hybrid III 6 year old child dummies.

Preliminary results suggest that properly restrained infants and children occupying age appropriate child seats may receive some protective benefits from side airbags provided the child seat and the child occupant are correctly positioned.

## **INTRODUCTION**

Side airbag testing was initiated by Transport Canada in 1998 as part of a larger side protection test programme that included studies in vehicle compatibility and moving deformable barriers (MDB). Airbag studies addressed protective benefits of side airbags for the head, neck and chest of properly positioned drivers and rear passengers in LTV to car collisions. Results of these studies are being presented in an accompanying paper [1].

An extensive series of out-of-position tests with side mounted airbags was carried out to evaluate the risks posed to children who were leaning against the airbag module at the moment of deployment. As the increased injury risk became evident [2,3] testing of in-position child dummies, restrained in child seats was initiated to determine if properly restrained children could be seated next to a side airbag without increasing the risk of injury.

There have been no injuries to children from side airbag deployments reported to date. However, given the concern for injury risk that has been generated from the out-of-position testing, Transport Canada has adopted a proactive approach with side airbags in an attempt to maximize benefits and reduce injury

risk among Canadian motor vehicle occupants. This paper reports on the findings of the in-position tests that have been on-going at Transport Canada since 1999. Preliminary results of the initial tests conducted in this study were presented at Stapp in Atlanta, Georgia [2]. Additional, more conclusive results are presented here.

The objectives for the study are to offer scientifically based recommendations to enhance the safety of child occupants in vehicles equipped with side mounted airbags by:

1. Evaluating the risk of injury to restrained child occupants exposed to statically deployed side mounted airbags.
2. Evaluating the effectiveness of side mounted airbags for restrained children exposed to side impact crash conditions.

## **METHODOLOGY**

### **Vehicle Selection and Preparation**

**Static Deployment Tests** The child seats were selected primarily on the basis of geometric profile. Child seats with a wide profile were preferred because it was assumed that these would create greater interference and result in greater interaction with the deploying airbag. The sample included one Evenflo rear facing infant carrier and two forward facing child seats, the Evenflo Ultara I Premier and the Century Room to Grow. Both seats were equipped with an overhead trays, had adjustable seat back angles and upper tether anchorages. The booster seat was a contoured full back, Century Bevera seat designed to be used as either a forward facing child seat with self contained retention harnesses or as a booster seat for the larger child. A clip to guide the routing of the upper torso belt was attached to the wings of the booster seat back.

Vehicles were selected on the basis of known airbag aggressiveness as determined from out-of-position

tests, airbag presence in the rear seat and the availability of curtain or tube technology. With the exception of the Toyota Camry which was a 1999 model all vehicles were year 2000 models. A matrix identifying the number of test conducted for each child seat type by vehicle model is presented in Table 1. Fewer tests were performed with the rear facing infant seat and booster seat because in many instances it was clear that no interaction between child seat and airbag was possible.

**Table 1**

**Summary of static deployment test matrix.**

	Rear Facing	Forward Facing	Booster
Audi A6	✓		
BMW 528i		✓	
Ford Explorer		✓	✓
Ford Focus		✓	
Ford Taurus		✓	✓
GM Cadillac de Ville	✓	✓	
Honda Accord	✓	✓	
Hyundai Sonata		✓	
Mercedes E-320		✓ ✓	
Nissan Maxima	✓	4	✓
Toyota Camry		✓ ✓	
Volvo S80		✓	
VW Jetta		✓	
VW Passat		✓	

Prior to placement of the dummy, test vehicles were leveled, placed in the design attitude and stabilized. Child seats were carefully inspected for signs of damage before installation into the vehicle and after each deployment. Deployed airbags were replaced with modules purchased from the respective

dealerships. In the case of seat mounted airbags, seat backs were either re-constructed using original replacement parts or replaced altogether. Vehicle interior trim where damaged was restored to original condition.

**Dynamic Tests** The child seat sample included the same seats as those employed for the static deployments. The rear facing infant seat however, was excluded from the dynamic series due to the lack of an appropriate infant dummy, instrumented for lateral measurements.

Vehicle selection for these tests was primarily restricted to vehicles equipped with side airbags in the rear seat though two Toyota Camrys were included in the matrix for baseline measurements. The test matrix identifying both bullet and target vehicles is presented in Table 2. The BMW 525i and Mercedes E-320 tests are still pending.

The three test configurations were as follows:

- the FMVSS 214 protocol which consists of a MDB crabbed at 27 degrees, and moving at 54 km/h;
- the European side impact protocol which employs a non-crabbed MDB moving at 50 km/h and
- the Ford Explorer used as a representative/ baseline SUV, crabbed at 27 degrees with an impact speed at 50 km/h .

**Table 2**

**Summary of dynamic side impact test matrix.**

Target vehicle / Bullet vehicle	Child Seat	Booster Seat
'99 Audi A6 / US MDB		✓
'00 Audi A6 / Ford Explorer 27°		✓
'00 BMW 528i / Ford Explorer <sup>1</sup>	<i>tbd</i>	<i>tbd</i>
'00 Cadillac / Ford Explorer 27°	✓	

<sup>1</sup> Test in progress

Target vehicle / Bullet vehicle	Child Seat	Booster Seat
'00 Mercedes E-320 / Ford Explorer <sup>1</sup>	✓	
'99 Toyota Camry / EEVC MDB		✓ <sup>2</sup>
'99 Toyota Camry / US MDB		✓ <sup>2</sup>

### Anthropometric child dummy selection

The Hybrid III 3 year old child dummy was used for both the forward facing and the booster seat configurations while the 9 month infant was used for in the rear facing carrier. One single test was conducted with the 6 year old Hybrid III.

Dynamic tests were carried out with the TNO Q3 3 year old as this was the only child dummy with lateral chest deflection measurement capabilities.

### Child seat installation and dummy placement

Rear facing infant seats were placed in the centre of the seating position and installed according to manufacturers instructions.

Forward facing child seats were installed as per manufacturers instructions. When placed in the front passenger seat, the top tether was attached to the anchorage location for the seat. In vehicles where anchorage locations were not available, tether straps were attached to the rear seat belt assembly. The child dummy was placed in the seat and restrained with the available harnesses as directed by the manufacturer.

Booster seats were generally placed in the centre of the seating position. Some variations were explored where the booster seat was shifted laterally against the door to create an obstruction for the airbag. In all tests however, the dummy was restrained with the vehicle 3-point belt.

The following photos illustrate the various child seat placements with accompanying child dummy positions.



**Figure 1 : Rear facing infant seat placement.**



**Figure 2: Forward facing child seat placement with 3 year old Hybrid III.**



**Figure 3: Top tether attachment in vehicle without tether anchorage.**

<sup>2</sup> Bevera booster seat used as forward facing restraint with harnesses



**Figure 4: Top tether attachment in vehicle equipped with a tether anchorage for the front seat.**



**Figure 5: Booster seat used as a child seat.**



**Figure 6: Hybrid III 3 year old in booster seat displaced laterally as far as possible.**

## Documentation of dummy position & motion

Dummy placement was digitized using the Bronze series FARO arm. The FARO arm is an articulated linkage device with electromechanical sensors at each joint. Absolute accuracy is  $\pm 0.3\text{mm}$  while the practical accuracy is closer to  $\pm 1\text{mm}$  when coordinate transformations are taken into account. Digitized data points included dummy landmarks, reference points on the child seat, airbag module, and the centreline of the vehicle seat. All points were referenced to the vehicle's fiducial coordinate system. Airbag interaction was filmed with high speed videos at a rate of 1000 frames per second in left and or right lateral views orthogonal to the mid-sagittal plane of the dummy. Multiple digital still images were obtained pre and post deployment.

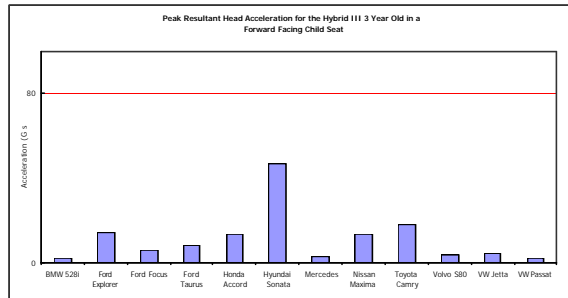
## Instrumentation and Filtering

The Hybrid III 3 year old dummy were each instrumented with a tri-axial accelerometer at the head CG, a 6-axis Denton load cell at the upper and lower neck, a linear chest potentiometer, upper and lower sternum accelerometers and tri-axial accelerometers at the upper, mid and lower spine (~T-1/ T-4/ T12). The dummies were grounded and sprayed with anti-static spray before each test. Data recording and filtering was performed in accordance with SAE J211.

## RESULTS

**Static airbag deployments** carried out with rear facing infant seats in either front or rear seats were completely uneventful. There was little if any interaction between the deploying airbag and the child seat and no physical contact with the infant dummy. This was true for seat mounted torso bags, the typically more intrusive seat mounted head torso bags as well as for door mounted systems.

Static deployments with forward facing child seats placed either in the front or rear seats caused very mild head accelerations. Dummy contact with the airbag was never observed. The bar chart in Figure 7 illustrates the innocuous head acceleration measurements recorded in these tests. Displacing the car seat to the outboard most location did not adversely affect dummy readings, in fact in the case of the Nissan Maxima for example, peak resultant head acceleration dropped to about 7 G s.

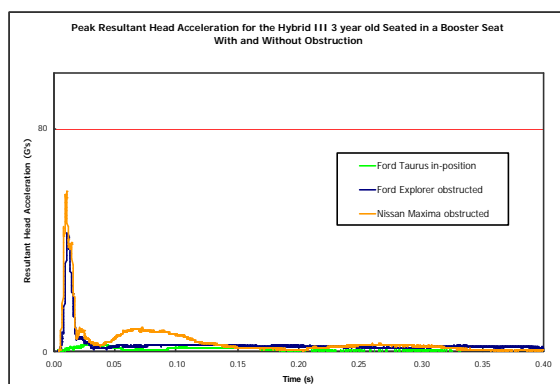


**Figure 7: Peak resultant head acceleration for the Hybrid III 3 year old in a forward facing child seat**

Interaction with the car seat occurred in all tests, though for most cases this did not result in any damage to the child seat. One exception was noted however, in the Nissan Maxima. The forward facing child seat was correctly installed in the front passenger seat however, the impact from the deploying head torso bag was severe enough to cause cracking of the child seat at the point of attachment (pivot point) of the overhead table. The crack extended into the main structure of the child seat. The test was repeated a second time with the same results. Head accelerations did, nonetheless, remain low at 14 G s and 17 G s for tests 1 and 2 respectively. There were no other notable dummy responses.

Airbags interacted very little with the correctly installed booster seats as there was sufficient space for the airbag to deploy.

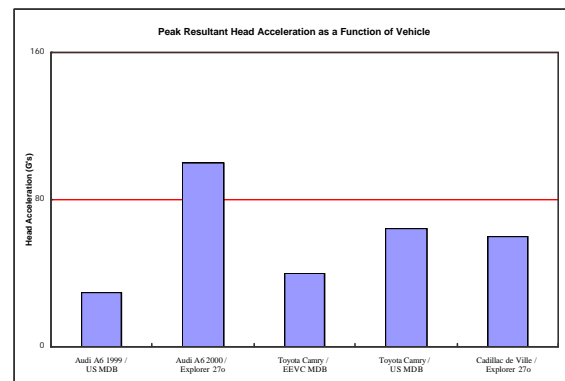
Booster seats were displaced outboard in an attempt to block the exit of the airbag with the seat back. As shown in Figure 8 below, only a relatively moderate increase in peak resultant head acceleration was observed in the displaced cases. There was no evidence of damage to the booster seat itself.



**Figure 8: Comparison of resultant head acceleration traces for in-position booster seat and displaced booster seat.**

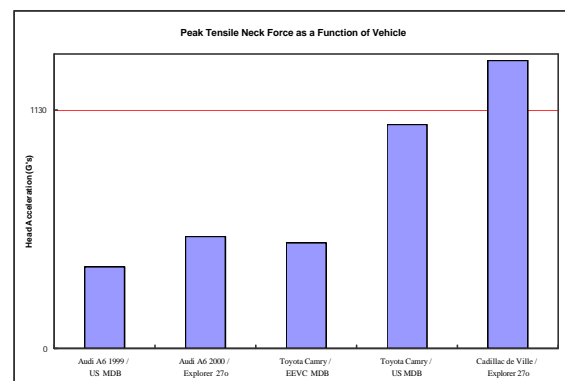
**Dynamic tests** carried out with correctly installed child restraints in the rear seats of vehicles equipped with side airbags were also quite encouraging.

Head accelerations shown in Figure 9, were generally low with the exception of the Audi A6/Explorer test. In this case the child dummy head is initially cushioned by the deployed airbag but the severity of the crash results in a bottoming out of the airbag. Hence the elevated head acceleration occurred when the airbag is overridden by the leading edge of the Explorer hood



**Figure 9: Peak resultant head acceleration for the TNO Q3 in dynamic tests as a function of vehicle.**

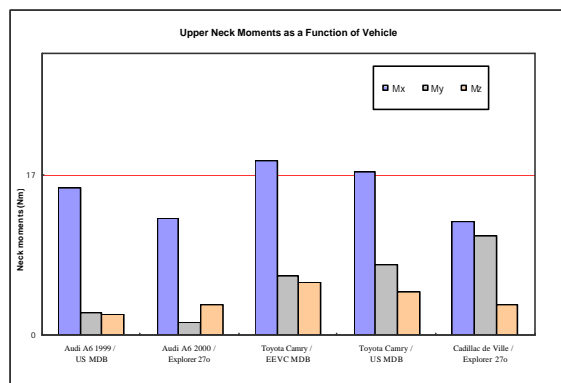
Peak neck tensile forces for the vehicle sample are presented in Figure 10. Neck tensile forces in the Audi A6 /Explorer test were comparatively low. Video images confirm that the head and neck appear to have been well supported throughout the crash event. In contrast, the neck tension results for the Cadillac de Ville / Ford Explorer test attained a magnitude of 1365 N. Similarly, the far less severe Camry / US MDB test reached a peak of 1061 N. The limit of 1130 is the recommended tensile limit for the Hybrid III 3 year old in out-of-position static tests [4].





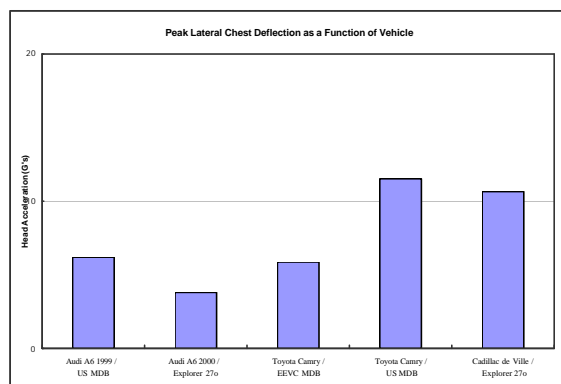
**Figure 10: Peak tensile neck force for the TNO Q3 in dynamic tests as a function of vehicle.**

Upper neck responses for the Q3 3 year old are presented in Figure 11. The 17 Nm limit indicated in the plot is the recommended criteria for neck extension and torsion. The limit for lateral neck bending (not shown in the plot) is higher at 30 Nm. Lateral neck moments were well below the 30 Nm injury limit recommended for the Hybrid III 3 year as were extension and torsional moments, in for all cases.



**Figure 11: Neck moments for the TNO Q3 in dynamic tests as a function of vehicle.**

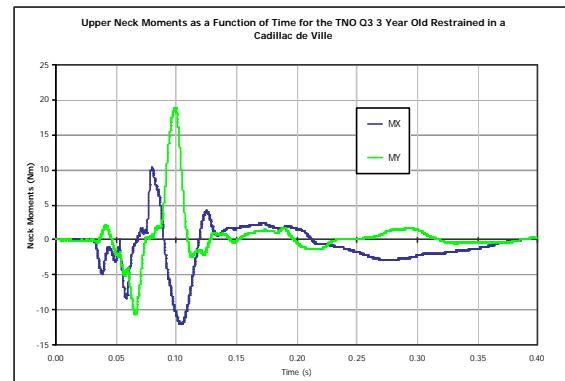
Peak lateral sternum deflection values are shown in Figure 12. Lateral chest deflection as measured at the sternum was low for all vehicles in the sample. A review of the high speed video indicated that the chest was being loaded obliquely rather than purely laterally. This was true for both the perpendicular and crabbed configurations.



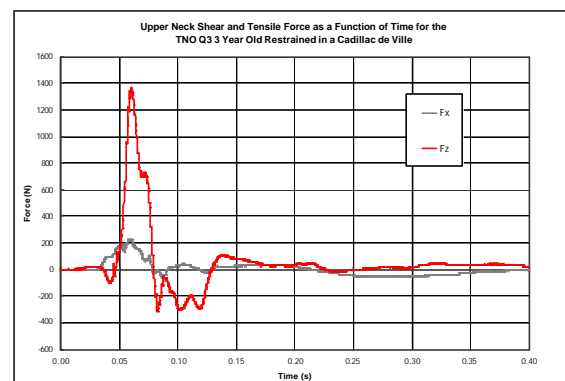
**Figure 12: Peak lateral chest deflection for the TNO Q3 in dynamic tests as a function of vehicle.**

Figure 13 and Figure 14 are sample traces of the upper neck responses recorded in the Cadillac de Ville. There is a positive lateral bending peak

moment of 10 Nm occurring at 81 msec followed by a negative lateral bending peak of 12 Nm at 104 msec into the event. The upper neck moments peak in extension (10 Nm) at 66 msec followed by flexion (19 Nm) at 99msec. Tensile force clearly predominates over shear forces in this case with a peak of 1365 N at approximately 60 msec.



**Figure 13: Upper neck moments as a function of time for the TNO Q3 seated in a forward facing child seat in a Cadillac de Ville**



**Figure 14: Upper neck shear and tensile force as a function of time for the TNO Q3 seated in a forward facing child seat in a Cadillac de Ville**

## DISCUSSION

Static deployment test results are quite encouraging. The child seats appear to be quite effective and isolating the child dummy occupant from any potential interaction with the side airbag. Certainly all of the tests would represent the ideal circumstances. There is no pre-crash displacement, the child seats are properly secured in place and the child occupant is seated perfectly upright. The dummy is too stiff to simulate typical child postures such as leaning the head against the child seat bolster however, the tests do show that the child seats

included in the sample were capable of distributing the applied load sufficiently to minimize recorded responses.

There is no doubt that more pliable, more human like child dummies, equipped with dedicated instrumentation for these types of applications would be extremely valuable. Until such time as the dummy designs improve however, field data will need to be closely monitored to ensure that the test methods, including the dummy instrumentation, are adequately evaluating the airbag systems.

There was very little if any interaction between the rear facing infant seat and any of the airbags tested, likewise there was no interaction with correctly positioned booster seats. Structural damage was observed in only one test configuration with one seat model. Further testing would be helpful in determining what, if any seat types may be adversely affected by this airbag system. Rear facing infant seats and the Beverra booster sets were not affected by the airbag, even when displaced.

The forward facing child seats and booster seats performed well in all dynamic side impact crashes. The child restraints appeared to successfully shield the child occupants from direct contact with intruding structures.

The side airbag in the Cadillac de Ville does not appear to have played a major role in injury reduction. In fact the airbag could not be seen deploying beyond the child seat. Deployment was confirmed electronically and during post crash inspection. The more aggressive Audi seat mounted torso bag in contrast, likely made a difference to the injury outcome in the Explorer test as the child dummy was observed to be cushioned by the bag, if only through the initial phase of the crash event. The airbag deployed in a timely fashion and was appropriately placed to provide protection to the head and neck. The earlier test of the Audi A6 sedan with the US barrier also resulted in a timely deployment with good head and neck protection available to the dummy. In this case the test was less severe so it was difficult to evaluate how much of a benefit the airbag really was.

Chest response and the protection afforded to this region by either the child seat or the airbag was more difficult to evaluate. Loading of the chest in a rear seat occupant tends to be more oblique than pure lateral. Current dummies such as the TNO Q3 can provide lateral deflection measures or frontal deflection measures but not a combination of both.

Recent modifications to the TNO Q3 may resolve this problem. Though not yet released the modified Q3 would have a more compliant rib cage and be equipped with infrared tracking capabilities to measure deflections. Further development of child dummy measurement capabilities are needed to keep abreast of the advances taking place in testing protocols. Child dummies are increasingly being included in crash test matrices as an alternative to the 50<sup>th</sup> percentile male in efforts to ensure that all occupants are adequately protected in vehicles, regardless of size.

## CONCLUSIONS

The series of tests described here have provided the necessary information for Transport Canada to develop some preliminary guidelines for parents and guardians. So far, results suggest that there should not be any significant increase in the risk of injury from side airbags for properly restrained children, seated in child seats. Furthermore, due in part to the limited market penetration of rear side airbags and in part to the characteristics of side airbags installed in rear seats this risk is further reduced when the child is correctly restrained in the rear seat.

The dynamic test results presented, though limited to a very small sample of crash tests, are promising. Initial findings suggest that side airbags have the potential of reducing head contact with the intruding vehicle. The benefits of side airbags as they pertain to the protection of properly restrained child occupants seated in the rear seat has yet to be fully established. It would appear from the static and dynamic testing that have been conducted thus far, that side airbags do not appear to increase injury risk to children who are correctly restrained in age appropriate child seats. Guidelines to maximize side airbag safety for child occupants, prepared by Transport Canada, can be viewed on the Transport Canada Web site at [www.tc.gc.ca](http://www.tc.gc.ca).

## ACKNOWLEDGEMENTS

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The opinions expressed and the conclusions reached in this paper are solely the responsibility of the

authors and do not necessarily represent the official policy of Transport Canada.

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